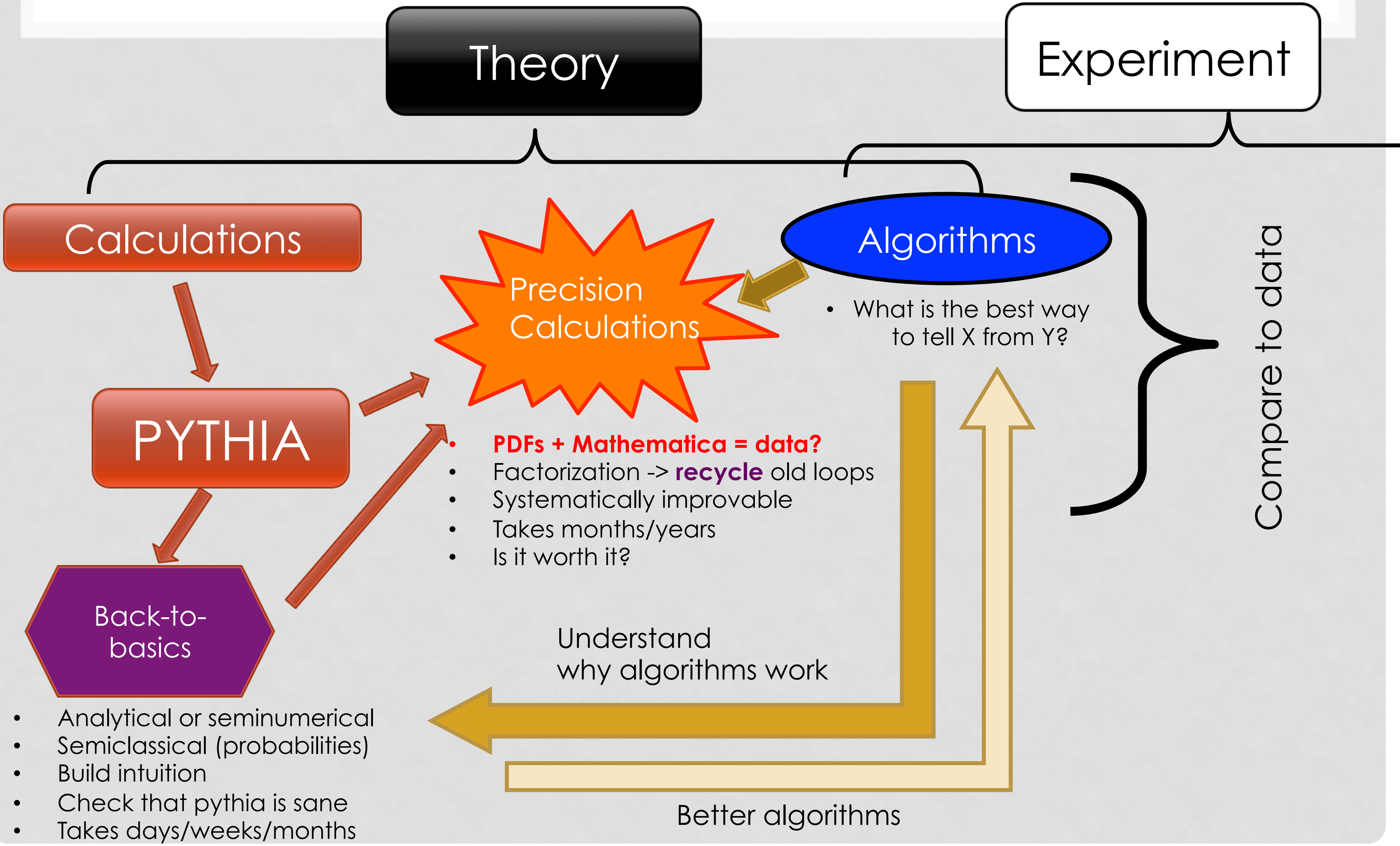
# BOOST 2013 THEORY SUMMARY

MATTHEW SCHWARTZ

# OUTLINE

- Overview
- 1-2 slide summary of each talk
- Summary
- Outlook

# OVERVIEW



Theory
Experiment
Calculations
Precision Calculations
Algorithms
What is the best way to tell X from Y?
Compare to data
PYTHIA
PDFs + Mathematica = data?
Factorization -> recycle old loops
Systematically improvable
Takes months/years
Is it worth it?
Back-to-basics
Analytical or seminumerical
Semiclassical (probabilities)
Build intuition
Check that pythia is sane
Takes days/weeks/months
Understand why algorithms work
Better algorithms

Back-to-basics

# JESSE THALER
## THEORY INTRODUCTION

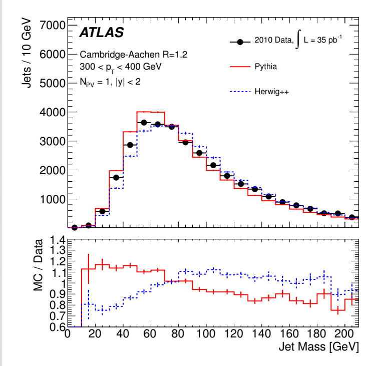
**(Calculations for Precision)**
*Unfinished Business from Boost 2012*

**Calculations for Insight**
*Back to Basics for Boost 2013*

**Calculations for Liberation**
*Thinking Beyond IRC Safety for Boost 2014*

Sudakovs factors and splitting functions
(semiclassical approximation)

$$\frac{1}{\sigma}\frac{d\sigma}{dm} = \frac{d}{dm} e^{-\frac{2\alpha_s C}{\pi} \triangle}$$




Works for pythia/herwig

| | IRC Safe? | IRC Unsafe? |
|---|---|---|
| Perturbative Control? | Yes<br>Order-by-order in $\alpha_s$ | Sometimes<br>e.g. Ratio Observables in $\sqrt{\alpha_s}$ |
| Non-Perturbative Input? | Yes: $(\Lambda/Q)^n$<br>e.g. Power Corrections | Yes: O(1)<br>e.g. Track Functions |

Sometimes:
Perturbative Handle

Motivate/understand observables

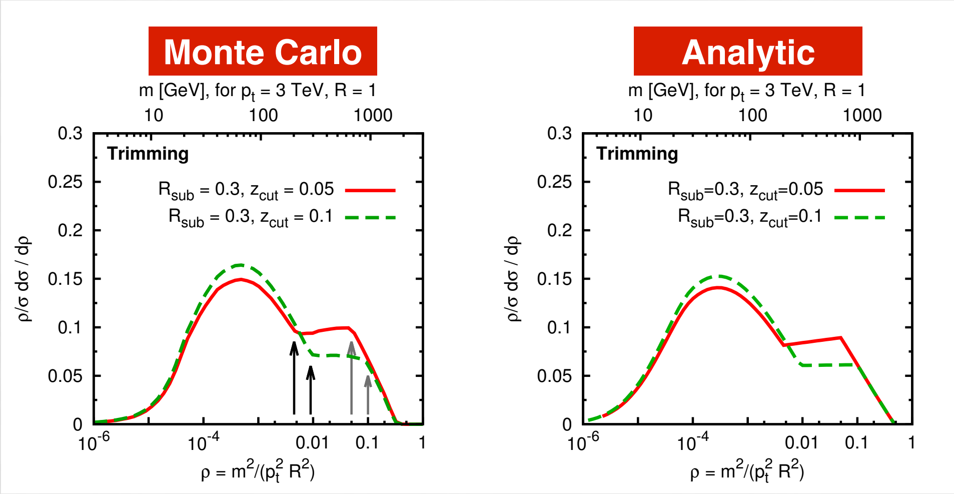
- How do algorithms work?
- Improve observables?
- Is pythia sane?
- Are some observables more theory friendly than others?

Back-to-basics

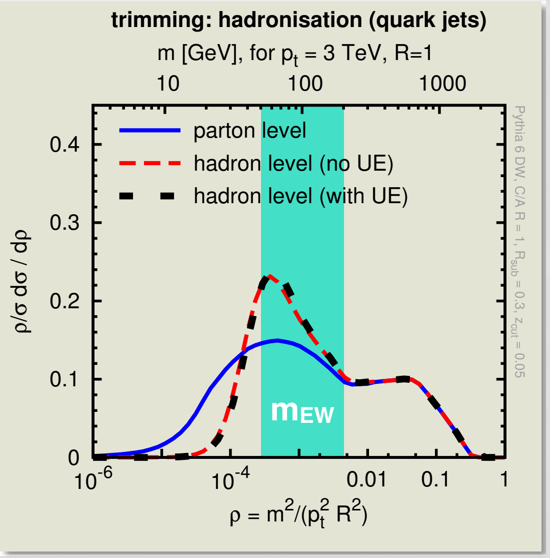
# GAVIN SALAM

## TOWARDS AND UNDERSTANDING OF JET SUBSTRUCTURE

Trimmed mass distribution reproduced from Semiclassical calculation




Hadronization important
UE not (trimming works)




- has non-trivial structure, relevant for phenomenology
- can mostly be understood from LO calculation & standard resummation techniques — quite similar to jet mass
- non-perturbative effects are relevant

Impressive analytic understanding of trimming

Back-to-basics

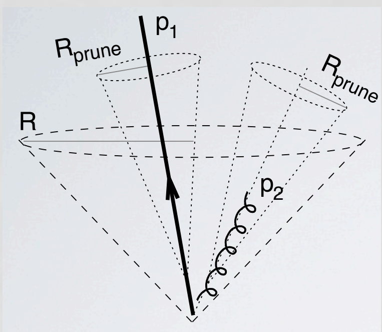
# SIMONE MARZANI

## PRUNING AND MASS DROP WITH ANALYTICAL METHODS

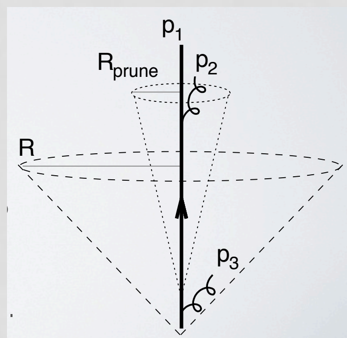
Pruned mass distribution reproduced from Sudakov calculation

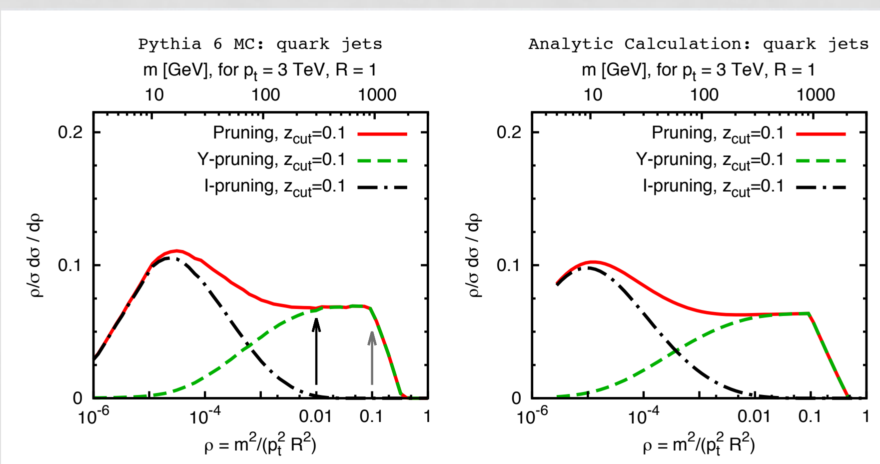
• A simple modification: require at least one successful merging with $\Delta R > R_{prune}$ and $z > z_{cut}$ (Y-pruning)

Y-pruning

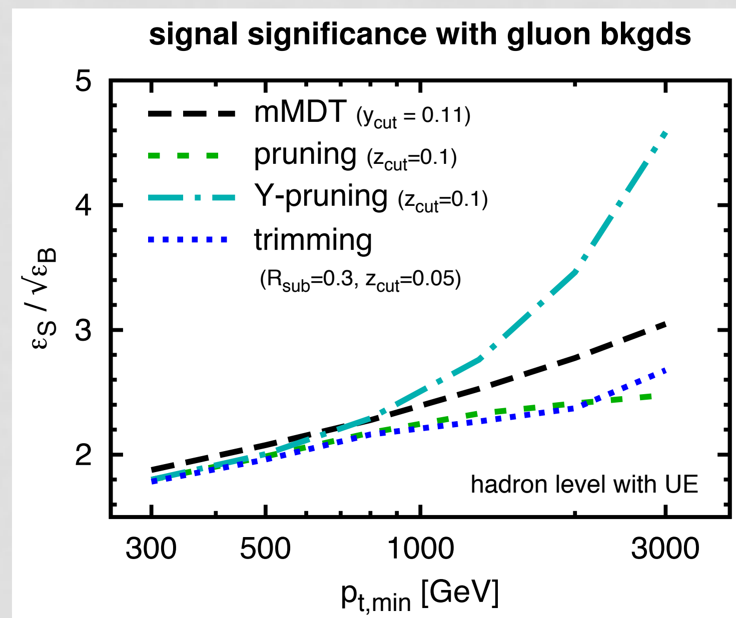



I-pruning




Y-pruning improves significance

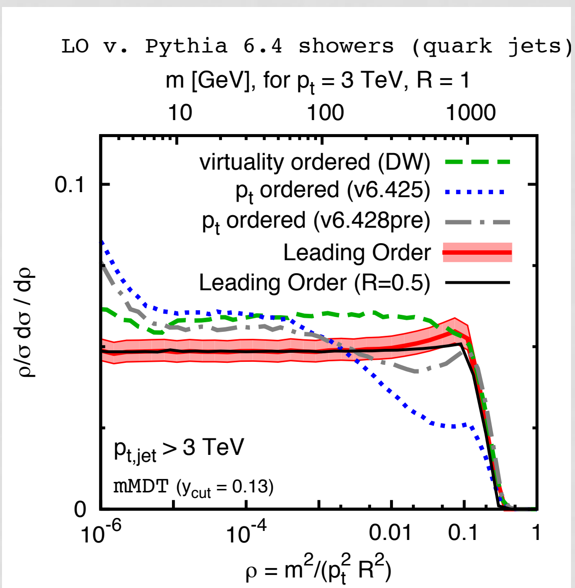


Back-to-basics

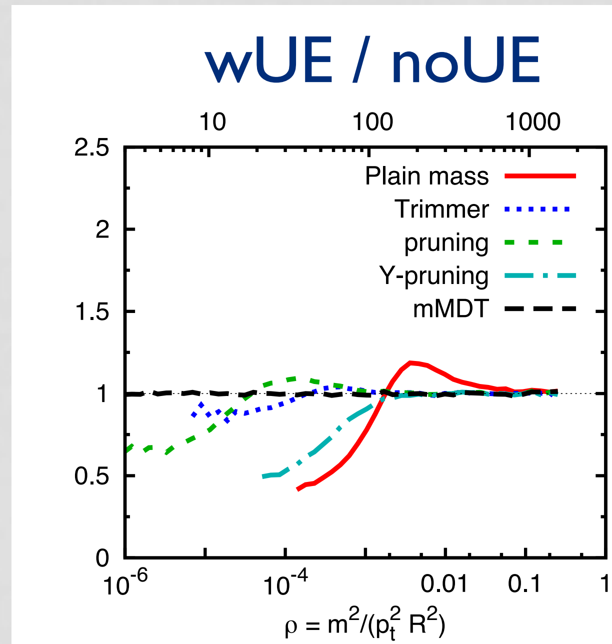
# SIMONE MARZANI

## PRUNING AND MASS DROP WITH ANALYTICAL METHODS

- Mass drop distribution hard to compute
- Modified mass drop (mMDT): uses **transverse mass** to pick subjet
- Only collinear not soft-collinear emissions




Found bug in Pythia 6!




mMDT has remarkable properties

- **Insensitive to UE!**
- Free of non-global logarithms

# ROBERT SCHABINGER

## SOFT NON-GLOBAL STRUCTURE AT TWO LOOPS IN SOFT-COLLINEAR EFFECTIVE THEORY

Precision calculations

- Non-global structure limits theory precision
- Numerically, similar to NNLO effects
- Analytic calculations of non-global logs (NGLs) show universality

$$C_F C_A \left[ -\frac{8\pi^2}{3} \ln^2\left(\frac{\tau_\omega Q}{2R\omega}\right) + \left( -\frac{8}{3} + \frac{88\pi^2}{9} - 16\zeta_3 \right) \ln\left(\frac{\tau_\omega Q}{2R\omega}\right) \right]$$

$$+ C_F n_f T_F \left( \frac{16}{3} - \frac{32\pi^2}{9} \right) \ln\left(\frac{\tau_\omega Q}{2R\omega}\right) + \cdots$$

Same non-global structure with finite R as for hemispheres!

How universal is non-global structure?

Can NGLs be resummed analytically?

Algorithms

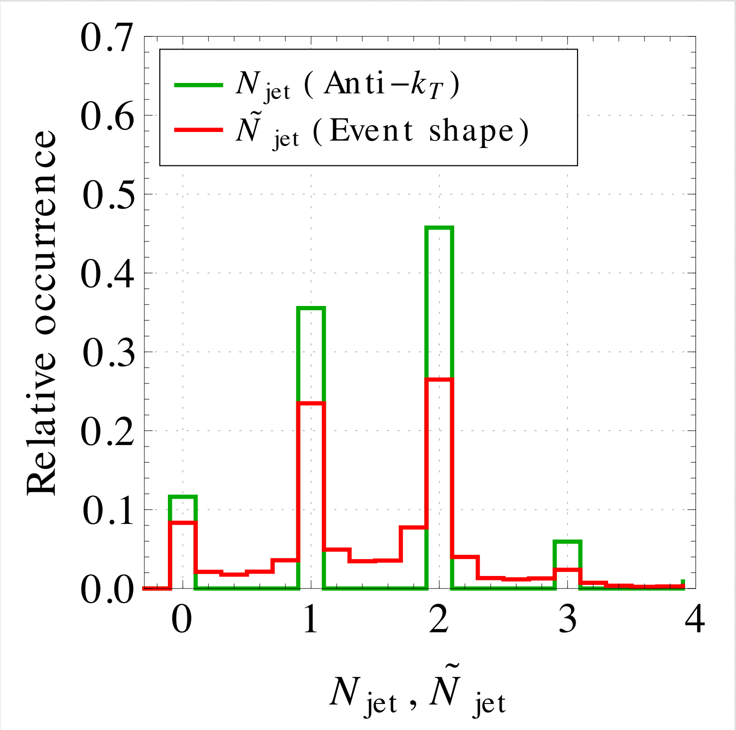
# DANIELE BERTOLINI

## JETS WITHOUT JETS

$$\widetilde{N}_{\text{jet}}(p_{T0}, R) = \sum_{i \in \text{event}} \frac{p_{Ti}}{p_{Ti,R}} \Theta(p_{Ti,R} - p_{T0})$$

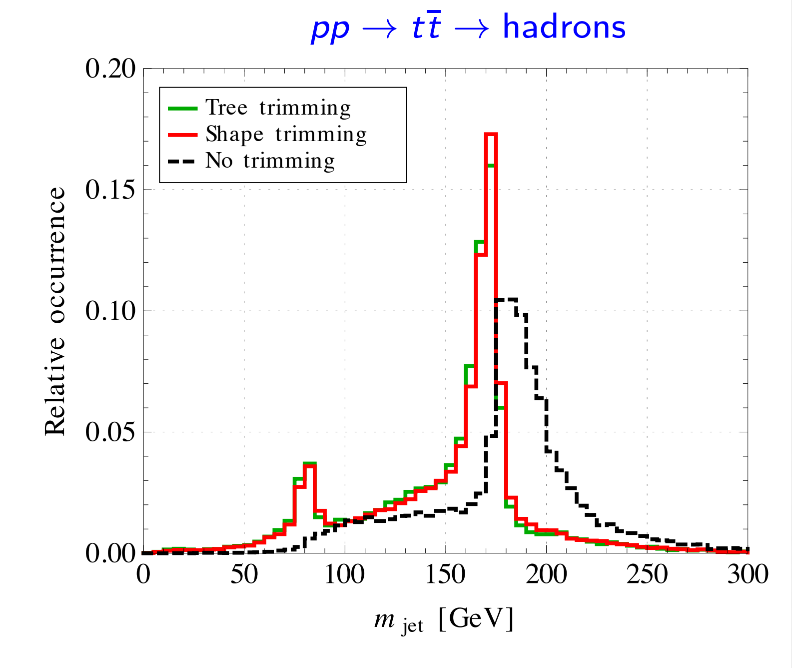
$$p_{Ti,R} = \sum_{j \in \text{event}} p_{Tj}\, \Theta(R - \Delta R_{ij})$$

Non-integer number of jets




$$\widetilde{t}^{\,\mu}_{\text{event}} = \sum_{i \in \text{event}} p_i^\mu \Theta\left(\frac{p_{Ti,R_{\text{sub}}}}{p_{Ti,R}} - f_{\text{cut}}\right) \Theta(p_{Ti,R} - p_{T0})$$

Trimming without trees




- Fast
- Local
- General definition of jet-like event shapes

Algorithms

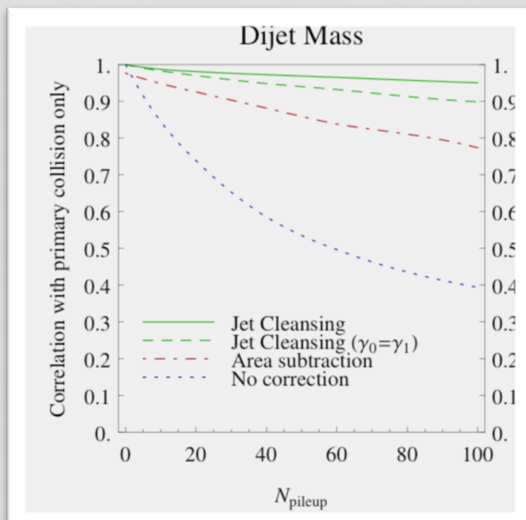
# MATTHEW LOW

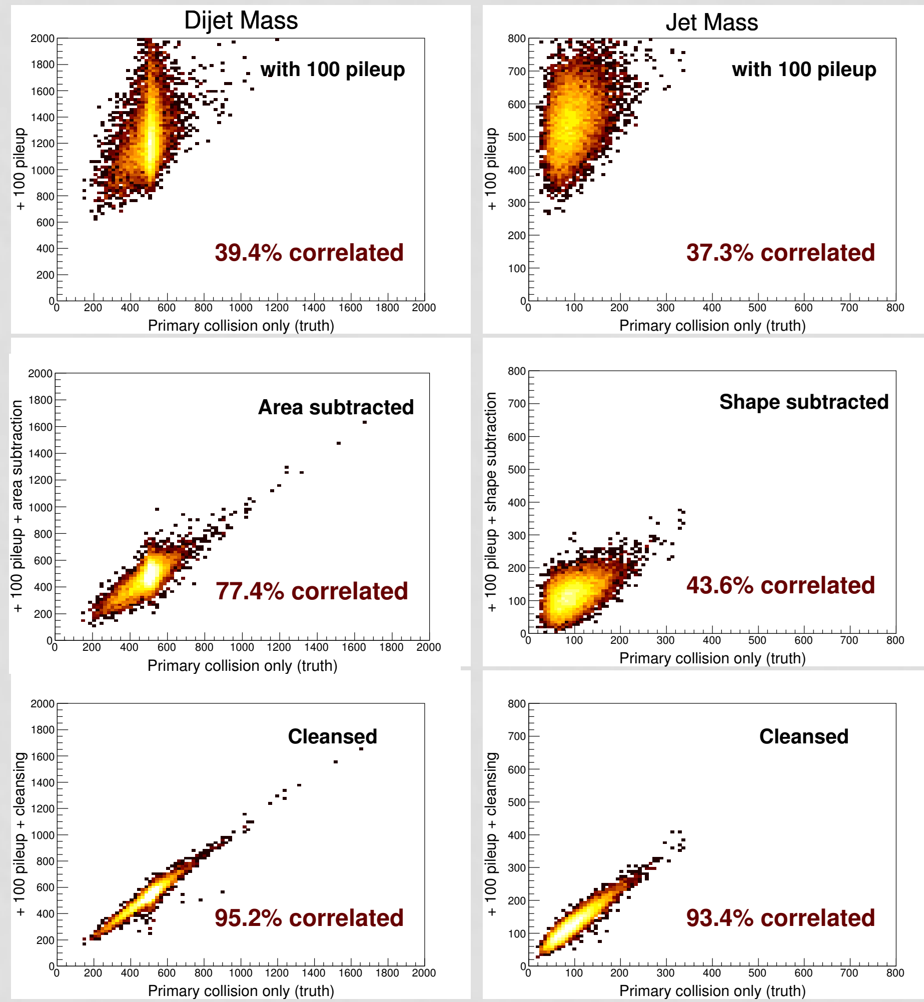
## JET CLEANSING

Rescale momenta using jet vertex fraction

$$p^{\mu} \to p^{\mu} \times \left( \frac{\gamma_{pv}^{-1} p_T^C(\mathrm{PV})}{\gamma_{pv}^{-1} p_T^C(\mathrm{PV}) + \gamma_{pu}^{-1} p_T^C(\mathrm{pileup})} \right)$$

- Apply clustering at **subjet** level
- Account for local variation of JVF
- Observable independent correction
- Works up to 150+ PU




"Useless!"
"Trivial!"
"We already did it!"

-- ATLAS,CMS

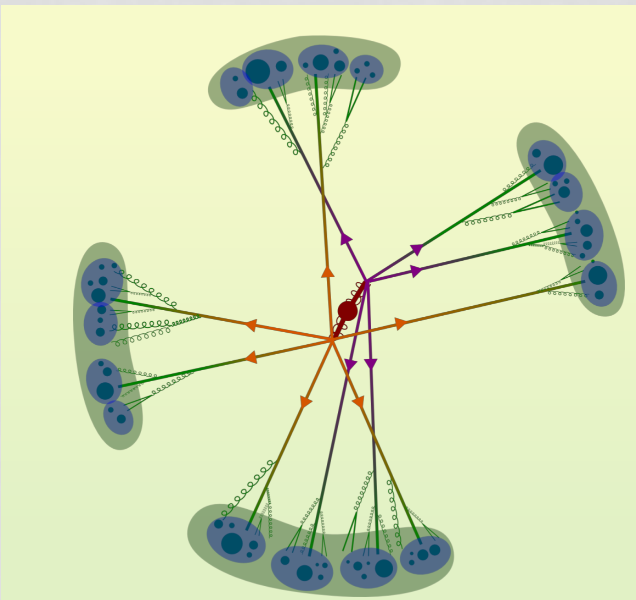
Algorithms

# TIM LOU

## JET SUBSTRUCTURE BY ACCIDENT

Sometimes 18 jets look like 4 jets

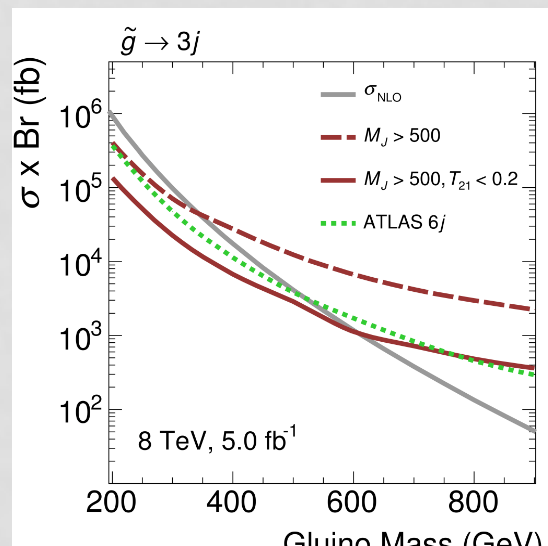
- Substructure accidental (not from boost)



Use combination of n-subjettiness ratios:

$$T_{mn} = \left( \prod_{j=1}^{4} \tau_{mn,j} \right)^{\frac{1}{4}}$$

- Competitive with ATLAS' skinny jet result

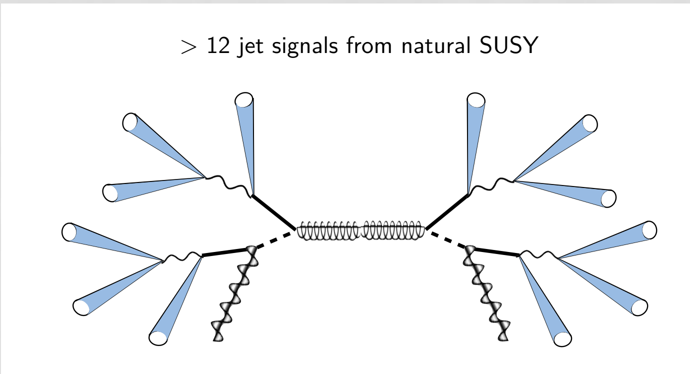


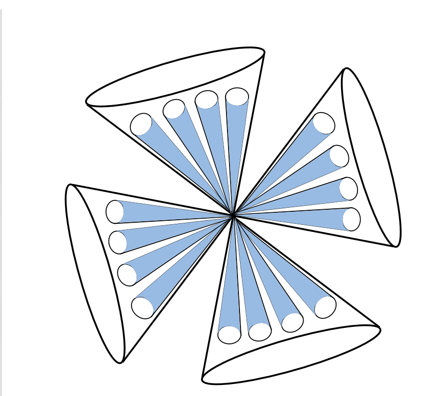

- Still cannot trust QCD calculation
- Data driven analysis?

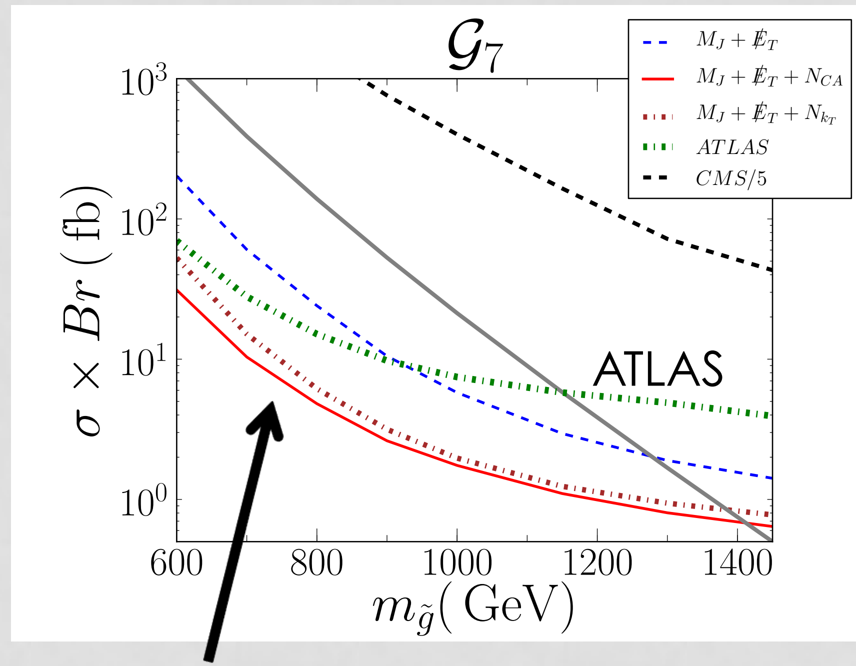
# SONIA EL HEDRI

## LEARNING HOW TO COUNT

Algorithms






With count variables

Can we count subjets within fat jet?

C/A or $k_T$ counting algorithms

Factor of 4-5 improvement in $\sigma$ x Br exclusion

Back-to-basics

# DAVE SOPER

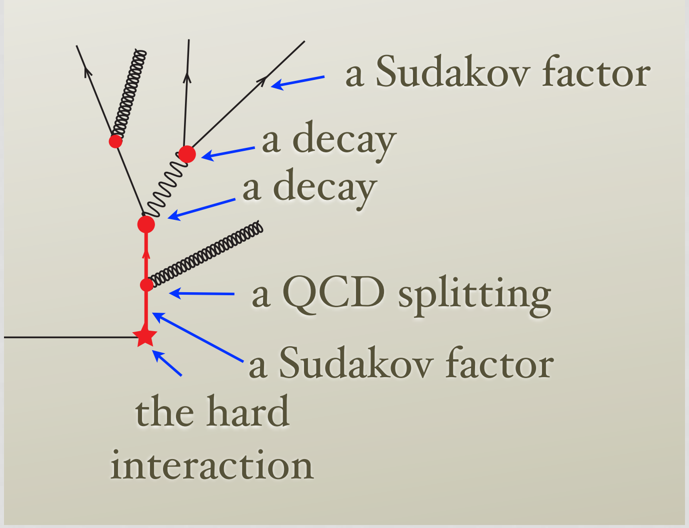
## SHOWER DECONSTRUCTION

Algorithms

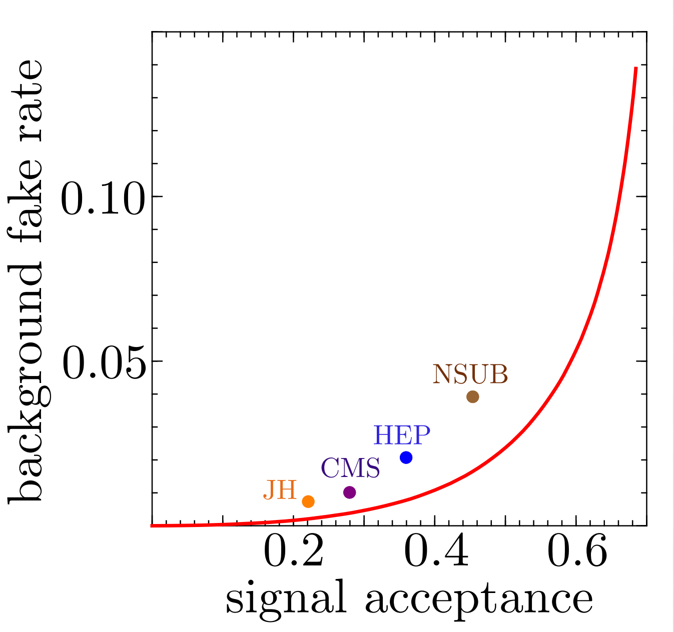
Calculate probability anaytically

$$\chi(\{p\}_N) = \frac{P(\{p\}_N|\mathrm{S})}{P(\{p\}_N|\mathrm{B})}$$

Using Sudkaov approximation




Works better than algorithmic top-taggers




- Similar to **matrix element method**
- Includes Sudakov factors, so **works for substructure**

Back-to-basics

Algorithms

# JEFF TSENG

## SEMICLASSICAL APPROACH TO JET CLUSTERING AND BACKGROUND SUBTRACTION

New clustering algorithm, with new distance measure

$$d_{ij} = \frac{1}{4}(m_{Ti} + m_{Tj})^2 \left(\frac{\Delta R_{ij}}{R}\right)^3$$

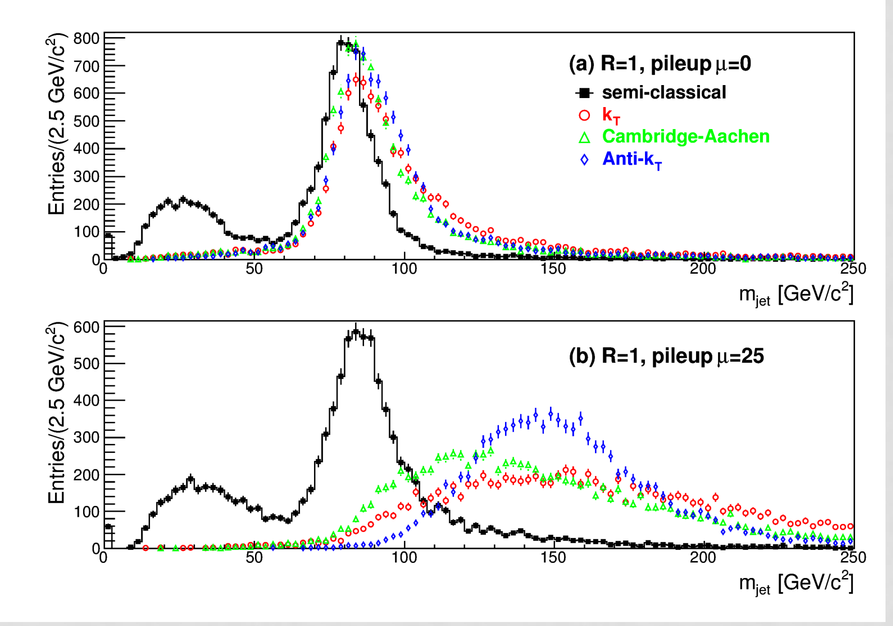
Motivated by semi-classical calculations

Based on transverse mass

$$m_{Ti}^2 = m_i^2 + p_{Ti}^2$$

$$\Delta R_{ij}^2 = \Delta \varphi_{ij}^2 + \Delta y_{ij}^2$$

Grooms and clusters at the same time



Back-to-basics

Algorithms

# ANDREW LARKOSKI

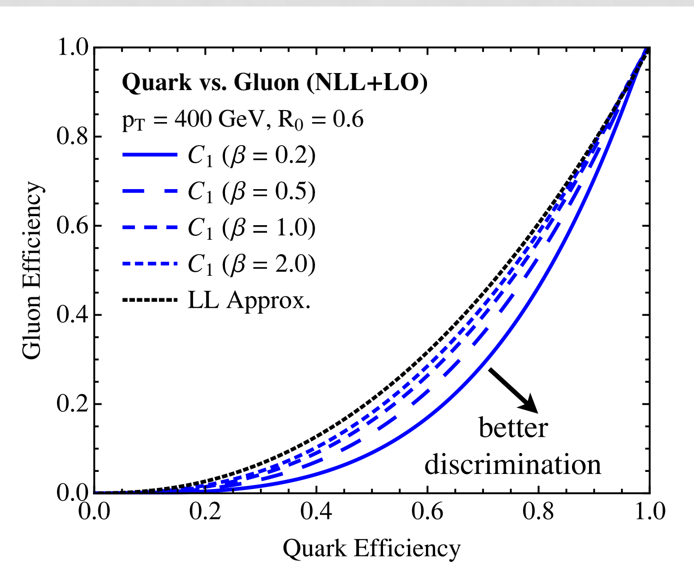
## ENERGY CORRELATION FUNCTIONS FOR JET SUBSTRUCTURE

Introduce n-point correlation functions

$$\mathrm{ECF}(2,\beta) = \sum_{i<j\in J} p_{T\,i}\, p_{T\,j} (R_{ij})^\beta$$

$$\mathrm{ECF}(3,\beta) = \sum_{i<j<k\in J} p_{T\,i}\, p_{T\,j}\, p_{T\,k} (R_{ij}R_{ik}R_{jk})^\beta$$

Analytic calculations imply smaller β is better
For quark/gluon discrimination



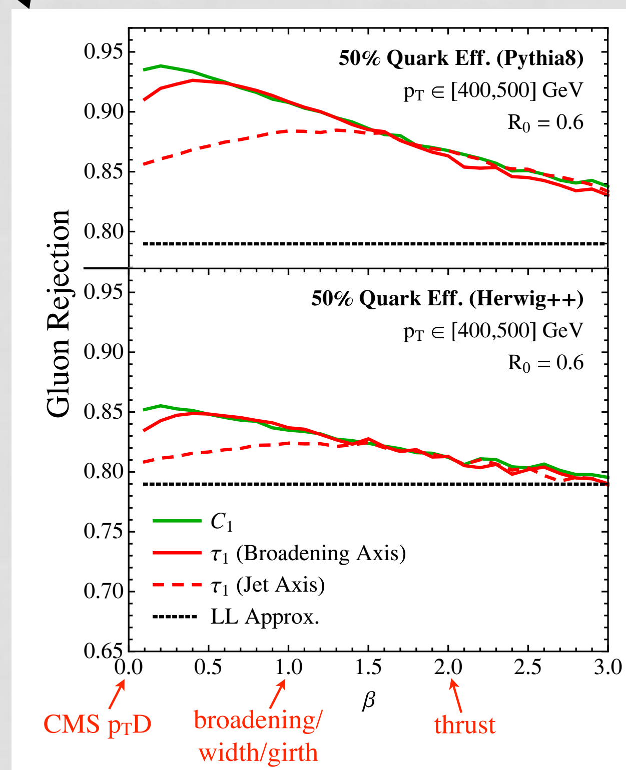

Recoil free at β=0

$$\tau^{(\beta)} \simeq z^\beta \theta^\beta + z\theta^\beta$$

"recoil" contribution

"direct" contribution

Helps with QvG



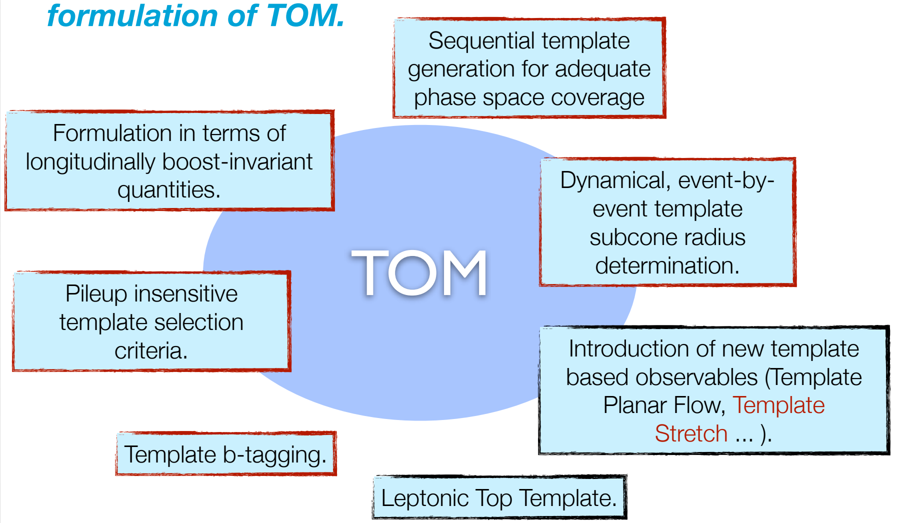
Algorithms

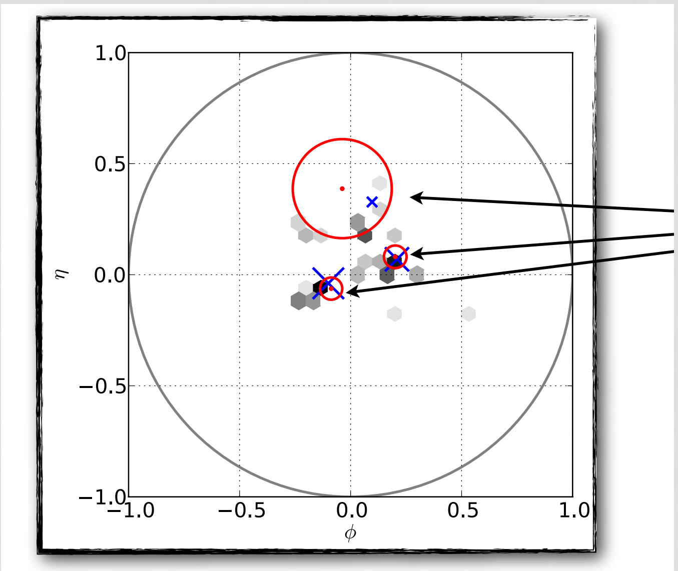
# MIHAILO BACKOVIC
## TEMPLATE OVERLAP METHOD

Compare event to 10,000 top or higgs events

Fatjet and subcones → Weakly sensitive to pileup

***Over time, many improvements were made on the original formulation of TOM.***




- Efficient method
- Tested on data

$$Ov = max_{(TS)}\left\{ exp\left[ -\sum_i \frac{1}{2\sigma_i^2}\left[\sum_j E_j - E_i\right]^2\right]\right\}$$

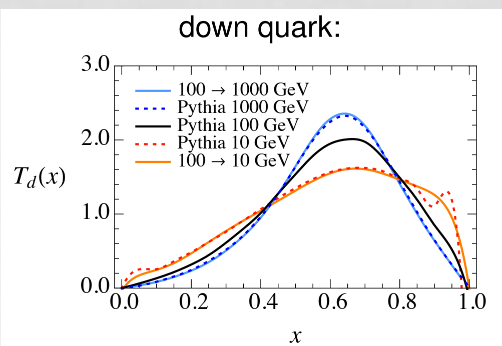
# WOUTER WAALEWIJN
## CALCULATING TRACK-BASED OBSERVABLES

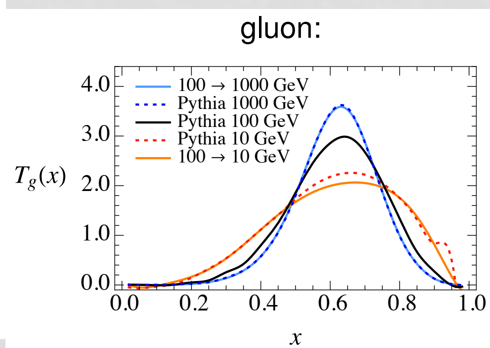
Precision calculations

**Pileup** is a big problem → Remove from data (subtraction, cleansing)
→ Calculate observables based only on tracks

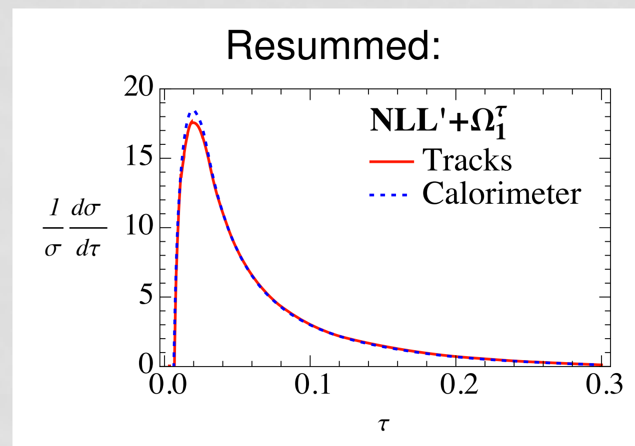
$$\mathrm{tr}\left[\frac{\gamma^-}{2}\langle 0|\psi(y^+,0,y_\perp)|CN\rangle\langle CN|\overline{\psi}(0)|0\rangle\right]$$

Track functions:
probability that fraction x of energy is in charged particle




- Requires more **non-pertubative input** than will all particles
- Harder to calculate with precision
- Can **measure more precisely**.
- Remarkably small difference from all hadrons

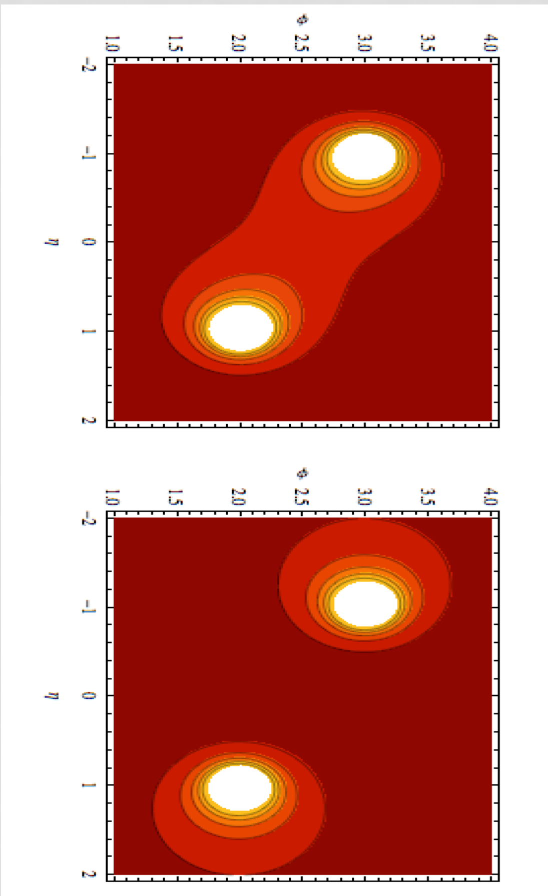


Algorithms

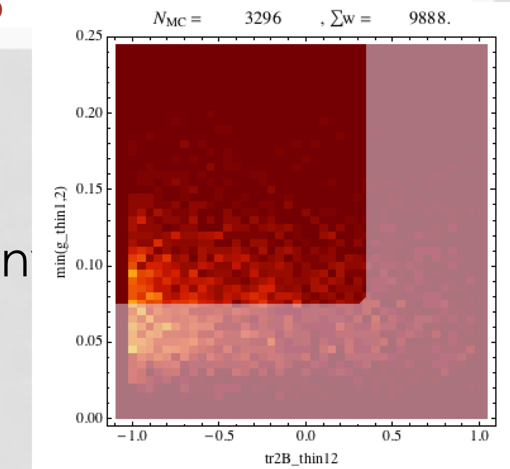
# DAVID CURTIN

## DIVORCING SOFT SUBSTRUCTURE FROM HARD KINEMATICS

Try to decorrelate
kinematic variables from showering variables



Looked at man
correlations




- The most useful variables fall into two separate groups:
  - N_charged
    girth
    thin jet mass
    dipolarity (color flow variable that weighs radiation along line connecting two jets)
    are correlated amongst each other with correlation ~ 0.5
  - radial pull (projection of pull angle along line connecting jets)
    axis contraction (change of $\tau_{21}$ axes with changing minimization measure)
    are correlated amongst each other with correlation ~ 0.7
  - correlation between these two groups is < 0.1

parton identity

bit of both?

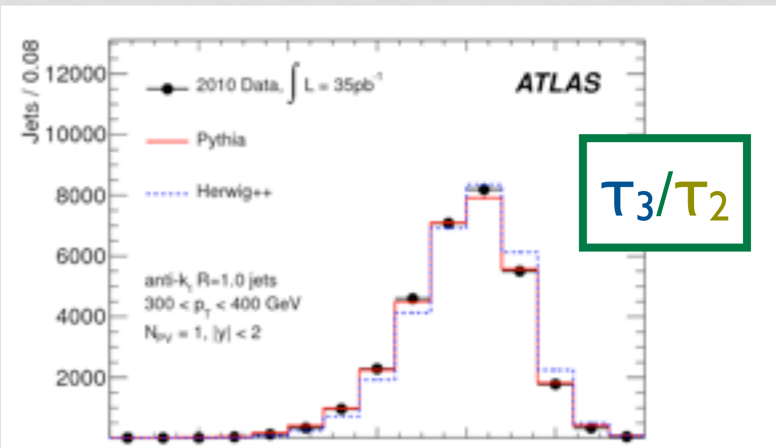
color connections

# JESSE THALER

## UNSAFE BUT CALCULABLE: RATIO OBSERVABLES IN PQCD

Back-to-basics

N-subjettiness ratios on QCD jets are not infrared safe




Simpler example: angularities

$$e_\beta = \frac{1}{E_{\text{jet}}} \sum_i E_i \left(\theta_i\right)^\beta$$

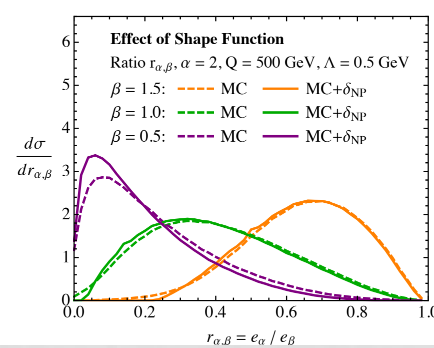
ratio $r = \dfrac{e_\alpha}{e_\beta}$ not infrared safe

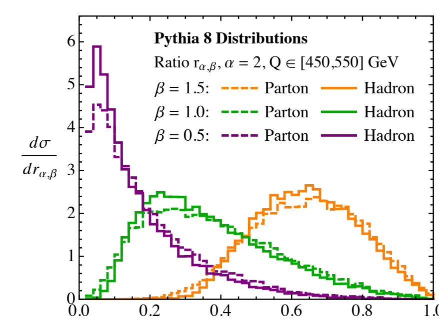
Ratios can be Sudakov suppressed near endpoint

**"Suadkov safe"**

Can reproduce qualitative features of Pythia analytically

MLL+LO+MC+$\delta_{NP}$ vs. Pythia 8



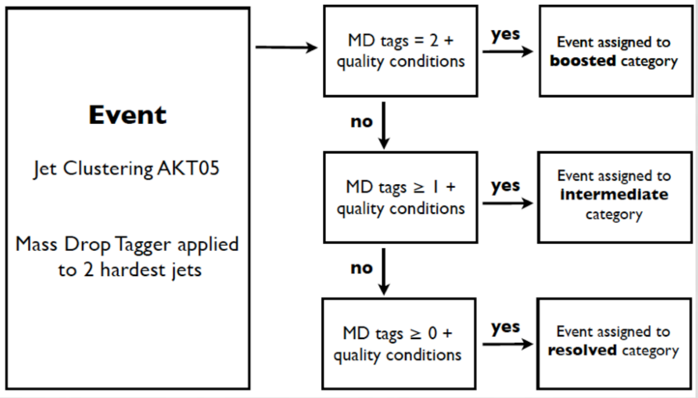



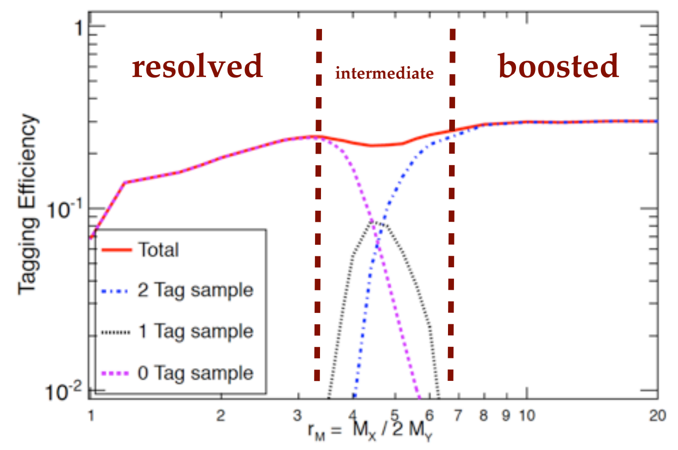
# GAVIN SALAM

## SCALE-INVARIANT RESONANCE TAGGING IN MULTIJET EVENTS

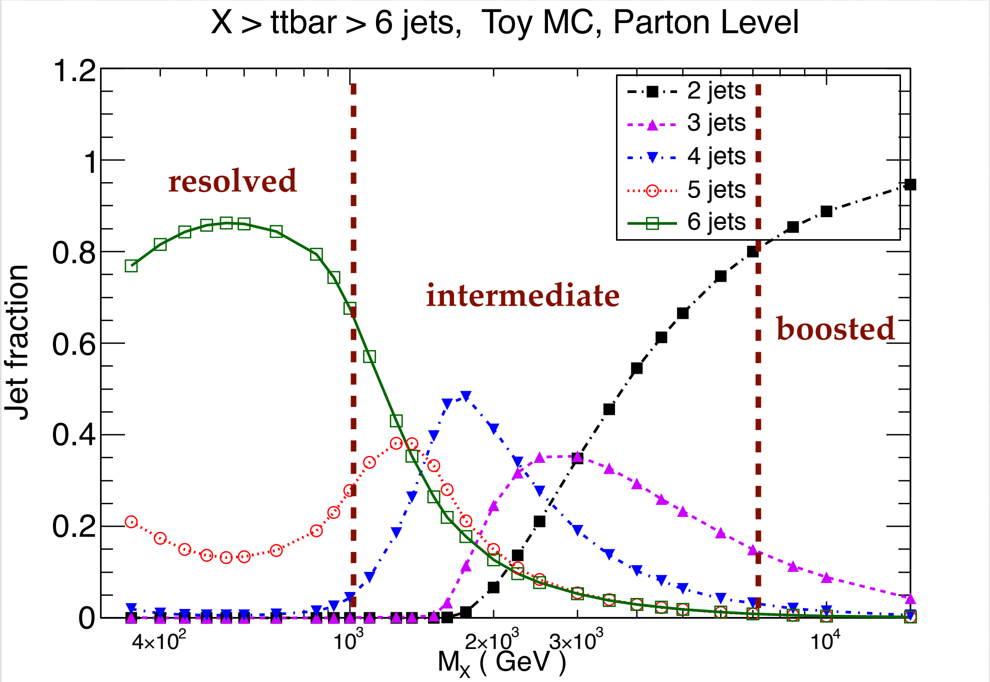
Algorithms

Smoothly interpolate between
Different kinematic regimes




Bring together different regimes
also for ttbar

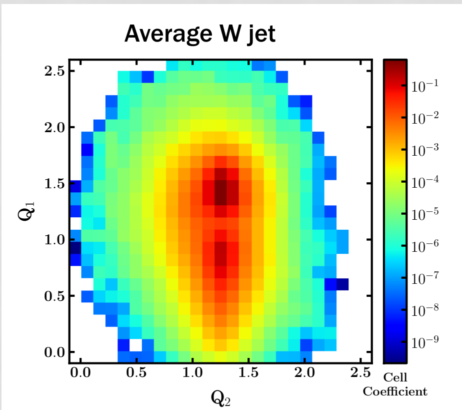


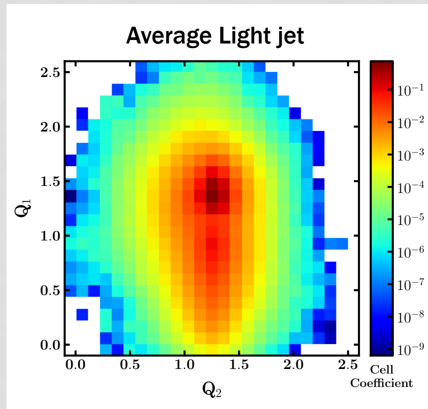
Algorithms

# JOSH COGAN

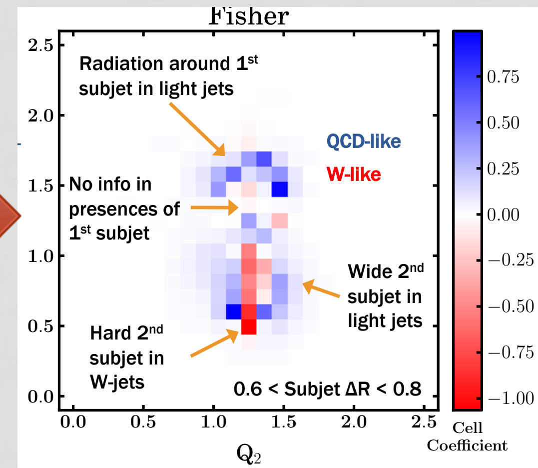
## APPLYING COMPUTER VISION TO JET FLAVOR IDENTIFICATION

Take as input pT in η ϕ plane



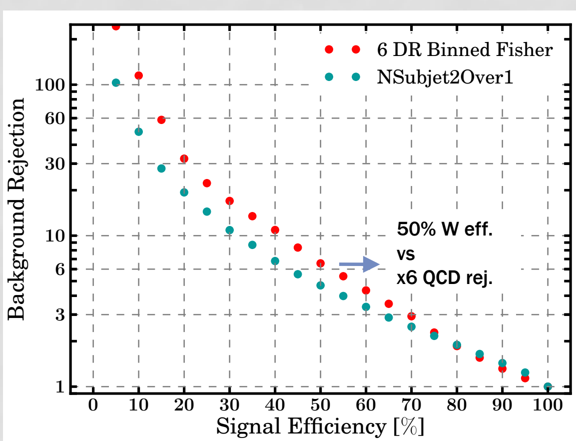




Fisher jet

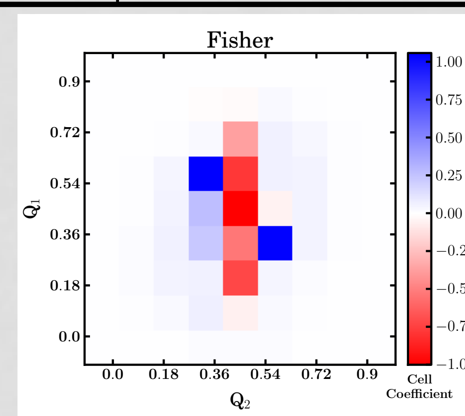



- Most important regions
- Incorporates correlations

Works better than n-subjettiness for W-tagging



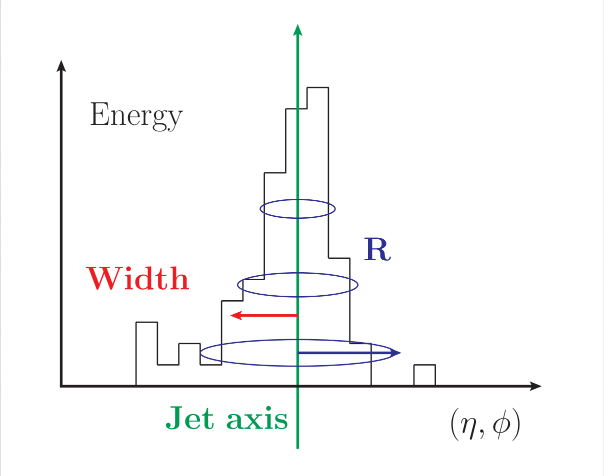

Gives insight Into Q v G discrimination



Algorithms

# YANG-TING CHIEN
## TELESCOPING JETS

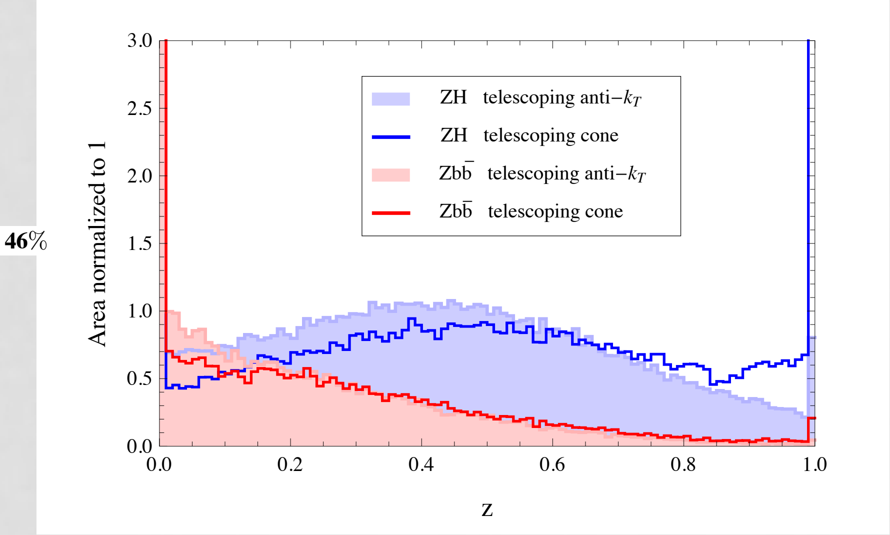
Jets do not have well-defined size




Consider multiple sizes

- Vary R's from 0.4 to 1.4
- Get weighted events (like Qjets)

z = fraction of R's which give mass in a window

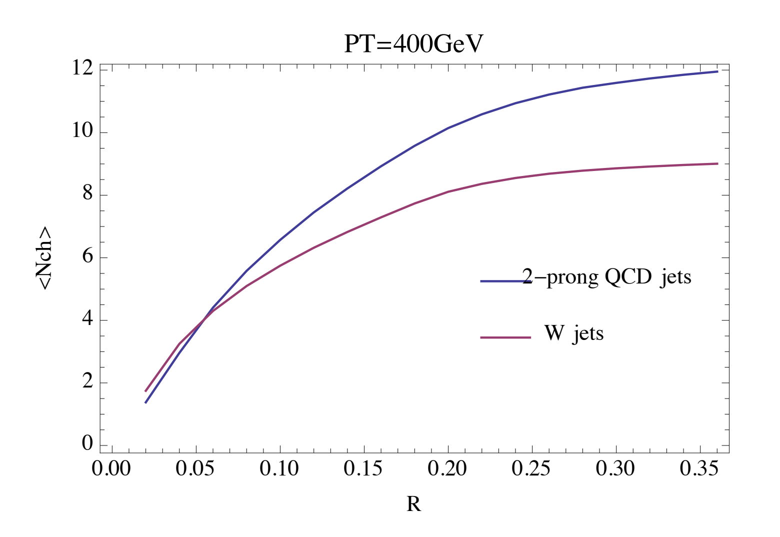



Using telescoping jet weights give 46% improvement in significance over cut-based analysis for H->bb

# ZHENYU HAN
## JET RADIATION RADIUS AND PILEUP

Algorithms

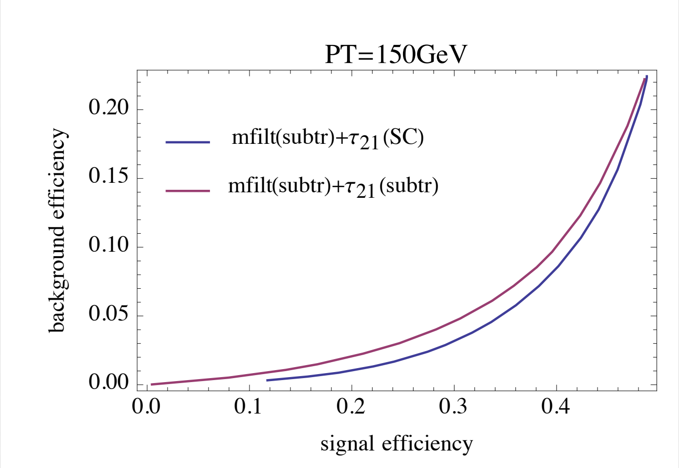
Radius of subjets shrinks with pT
Different for signal and background




- Find the axes of the two leading subjets, calculate $\tau_{21}$ for jet constituents with a cone around the two axes, (shrinking) cone size determined by

$$R_{\rm sub} = R_{\rm ref}\frac{100\rm GeV}{p_{T,\rm sub}}$$

Shrinking cone improves W-tagging



# SUMMARY

Precision Calculations

PDFs + Mathematica = data?

- What can we calculate?
- What should we calculate and why?
- What is the result of the calculation?

Simplified calculations for insight

Back-to-basics

- How and why do algorithms work
- What can we hope to calculate?

Algorithms

How to tell X from Y

- Many new, creative approaches
- General sense that even top-tagging still not optimal
- Proliferation of methods needs tidying?

# OUTLOOK

Past:

- Basic substructure algorithms
- First precision calculations (jet mass, $\tau 2/\tau 1$ signal)

Present:

- Sophisticated substructure algorithms
- Rethinking what can/should be calculated
- Understanding how algorithms work

Furture:

- Optimal algorithms?
- PDFs + Mathematica = data?

Substructure for BSM or precision SM physics